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Woods Hole Oceanographic Institution

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Use of the High Resolution Profiler (HRP) in the Brazil Basin Tracer Release Experiment

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Technical Report

Funding was provided by the National Science foundation
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Abstract

On two research cruises in 1996 and 1997 aboard the *R/V Seward Johnson*, scientists from the Woods Hole Oceanographic Institution participated in a study of the deep mixing processes in the Brazil Basin. Two instrument systems were used in this experiment: the tracer injection and sampling system, and the High Resolution Profiler (HRP). The HRP component of the work at sea, instrumentation, data return and some preliminary results are presented in this report.

The first cruise (96-01) departed from Rio de Janeiro, Brazil, on January 22, 1996 and returned to Recife, Brazil, on February 27 with most of the work occurring in the eastern part of the Brazil Basin. During the cruise, one patch of sulfur hexafluoride (SF6) tracer was injected successfully in the area around 21°42′ S, 18°28′ W, in a series of 8 streaks injected over 7 days. The patch was successfully sampled twice, verifying the initial tracer concentrations. The HRP was used to make two zonal sections across the basin, sample the injection site, and explore the mixing dynamics above the jagged seafloor near the Mid-Atlantic Ridge; 75 full depth HRP profiles were completed.

The second cruise (97-01) departed from Recife on March 13, 1997, and returned on April 18. The goal of this cruise was to sample and map the patch of tracer injected in 1996. By mapping the tracer's distribution one year after deployment, an indirect estimate of the rate and extent of diffusive mixing can be made. When possible, CTD casts and HRP profiles were done simultaneously to allow direct comparison of the data from the two instrument systems. A total of 77 CTD casts and 90 HRP profiles were completed, and within the accuracy of measurement, all the tracer deployed was found.

Overview

The first part of the Brazil Basin Tracer Release Experiment (BBTRE) took place in early 1996. The objectives of this cruise were to use the High Resolution Profiler (HRP) to complete an intial survey of the dissipation and diffusivity rates observed in the Brazil Basin, and to inject two patches of sulfur hexafluoride (SF6) tracer that would be sampled a year later. The tracer and HRP systems provide independent estimates of the turbulent mixing rate. The deployment and subsequent sampling of a tracer as it is mixed over time is an integrated way of estimating mixing. The sensors on the HRP allow discrete estimates of mixing to be made. Obtaining consistent estimates from two different methods gives a more convincing result than obtaining just one kind of estimate.

The injection cruise was highly successful despite minor instrument problems. Tracer injections were planned at two sites, but injection sled malfunctions made deploying tracer at the first site impossible, despite several attempts. The sled systems were debugged and working well by the end of the first cross-basin HRP survey. Using the HRP, a site with active deep mixing (at 21°42′S, 18°28′W) was chosen for the tracer injection. Eight streaks of tracer were successfully injected at 4000 meters depth at the site. Several neutrally buoyant pop-up floats were deployed to track the tracer movement. They were programmed to surface and transmit their positions after a year.

While surveying the basin for a suitable injection site and during the tracer injections and sampling, 75 HRP profiles were completed. HRP dives 1–8 were at the base of the Continental Shelf, in the area near the Deep Western Boundary Current. Dives 9–25 and 65–75 comprised two cross-basin sections. Dives 26–44 and 62–64 were completed as repeated surveys of a ridge near the tracer injection site. Areas of rough bottom topography on the western flank of the Mid-Atlantic Ridge were sampled in dives 45–61. A map of the Brazil Basin showing the locations of HRP profiles made during the cruise is shown in Figure 1. An enlargement of the injection site shows tracer injection streaks and locations of the floats deployed to follow the tracer.

The second part of the experiment occurred 14 months later, in the of spring of 1997. The goal of that cruise was to find the tracer injected in 1996 and to map its distribution. Bottle samples taken during CTD casts were analyzed using gas chromotography to quantify SF6 levels and distribution. The HRP profiles provided additional discrete estimates of diffusive mixing.

All the work of the second cruise was concentrated around the tracer injection site. The pop-up floats had surfaced and reported their positions in January 1997, suggesting rates and directions of movement of the water to which the tracer had been applied. A cruise plan was made that would thoroughly sample the area over which the tracer was expected to be distributed, based on the floats' data.

The HRP stations made on the sampling cruise are shown in Figure 2. They were contemporaneous with CTD casts whenever possible. The first 30 stations were made working eastward up a canyon approaching then leaving the injection site. Then the CTD winch failed, and ten HRP stations were made up and over the crest of the Mid-Atlantic Ridge with no accompanying CTDs. By dive 41 the winch was fixed, and the rest of the HRP profiles all have accompanying CTD data,

BBTRE year 1

BBTRE - Year 1

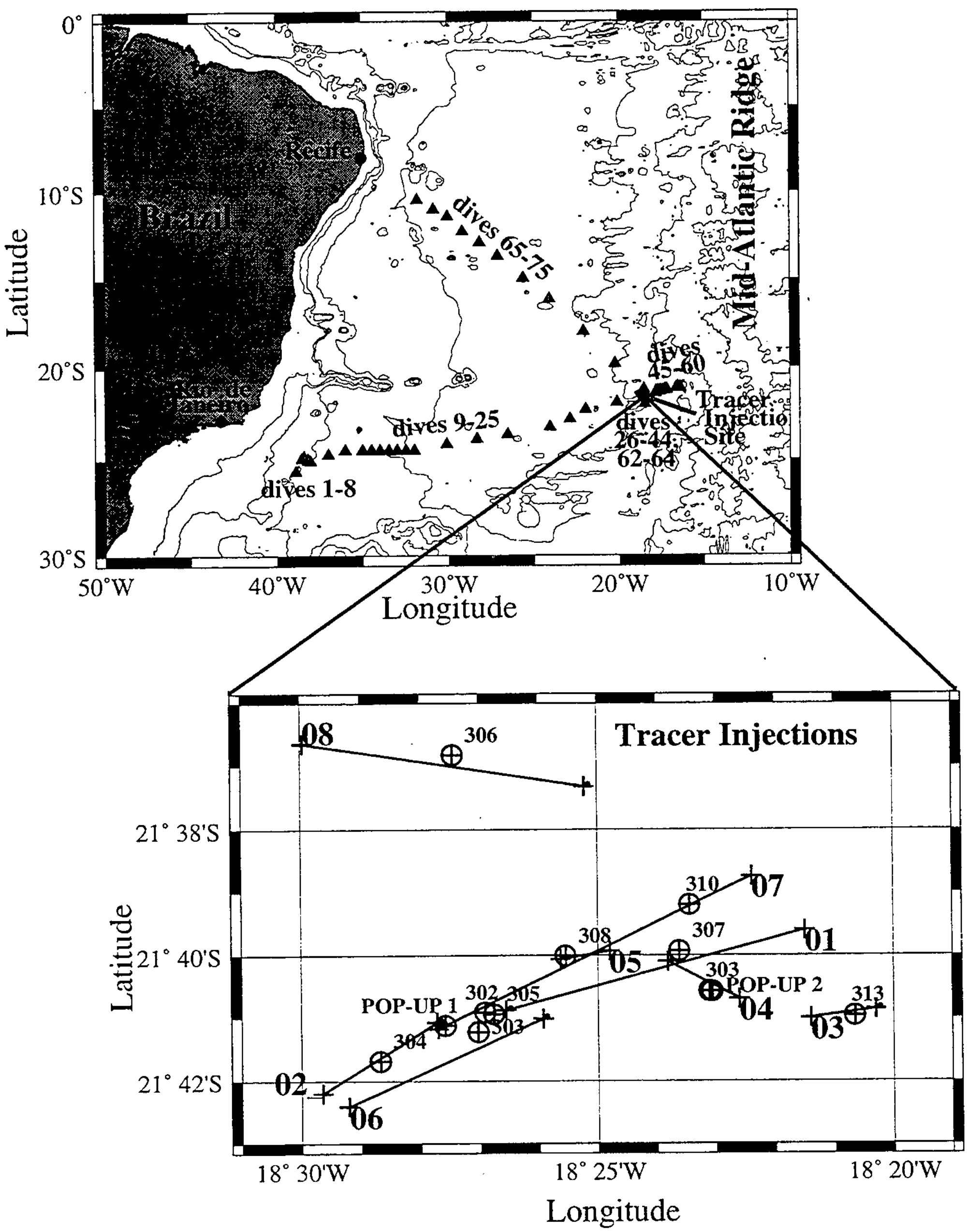


Figure 1: Chart showing the Brazil Basin injection cruise HRP dive locations. Enlargement shows the locations of the SF6 tracer injection streaks and the positions of the floats deployed to track the tracer.

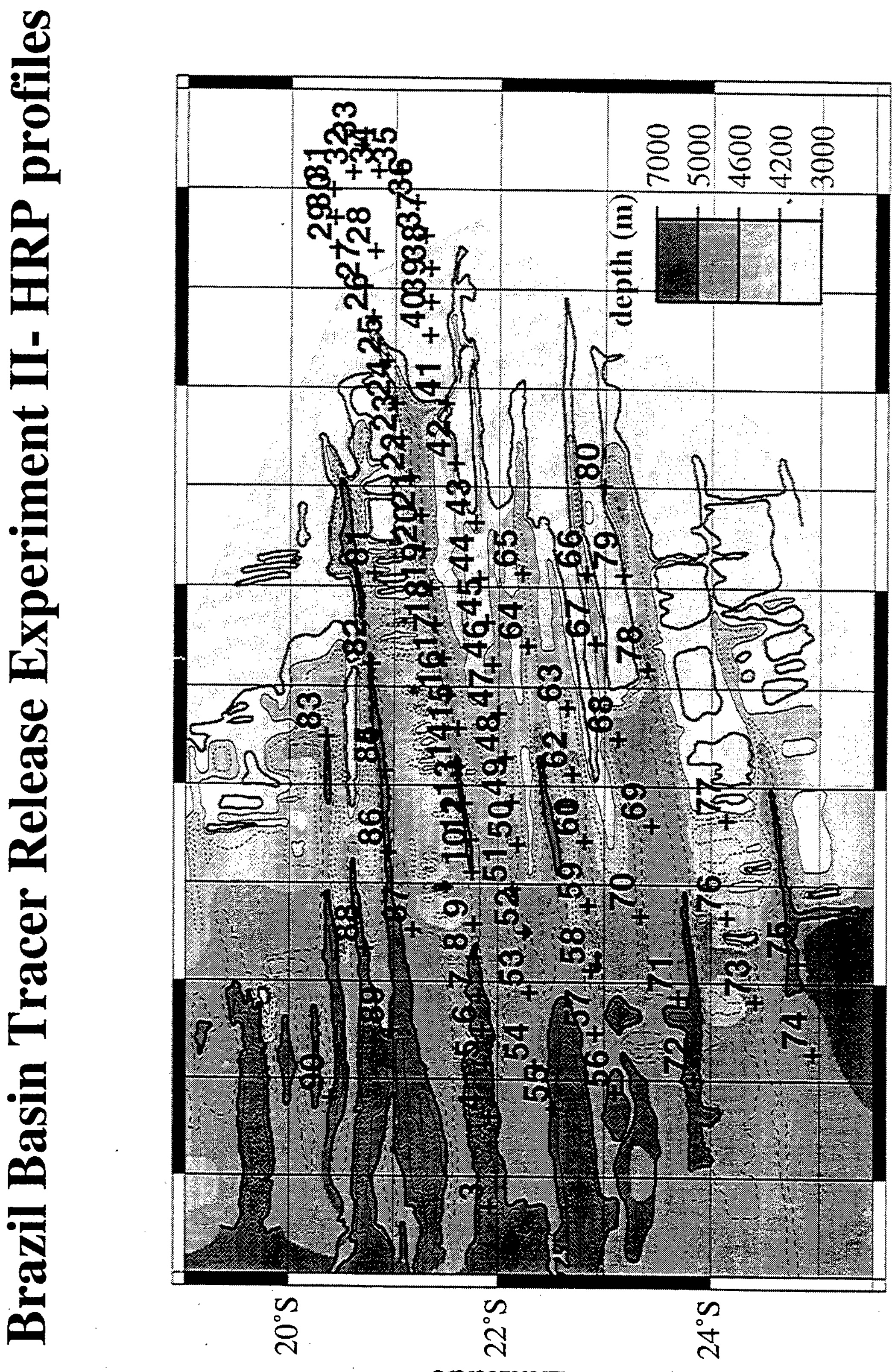


Figure 2: Chart showing the locations of HRP dives made during the sampling cruise

despite more winch problems. HRP dives 41–80 completed the southern part of the survey; then the final ten stations mapped the tracer distribution north of the injection site.

The emphasis of this report will be on the HRP work completed during both cruises: the tracer component will be documented elsewhere. A description of the HRP, cruise logs, data summaries and some preliminary results are presented in the sections following.

The scientists participating in this study are listed below; those who only made one cruise are noted.

Scientist	Affiliation	Instrument
Jim Ledwell	WHOI	Tracer - Chief Scientist
Terry Donoghue	WHOI	Tracer (year 1)
Brian Guest	WHOI	Tracer
Jeannine Sisson	WHOI	Tracer (year 2)
Suzanne Wetzel	WHOI	Tracer (year 2)
Stewart Sutherland	LDGO	Tracer
Ray Schmitt	WHOI	HRP
John Toole	WHOI	HRP
Kurt Polzin	WHOI	HRP
Ellyn Montgomery	WHOI	HRP
Dave Wellwood	WHOI	HRP
Tom Bolmer	WHOI	HRP
Lou St. Laurent	WHOI	HRP

Cruise Log – Injection Cruise – Year 1

The *R/V Seward Johnson* left Rio de Janeiro, Brazil at 1900h on January 22, 1996, in warm sunny weather. As we left the coast, that evening, we were treated to a spectacular show of thunder storms over land. A section across the continental shelf and slope was planned, but the Brazilian government did not grant the project clearance, so we transited directly to the site of the proposed first tracer injection (25.0°S, 38.58°W), arriving late on January 23.

Work commenced with the deployment and recovery of the weight that steadies the injection sled to demonstrate the capacity and reach of the ship's crane. When the sled weight was back on deck, two test deployments of the HRP were completed. The first was to 1000 meters to allow a review of operations and to find any component systems failures. The second was a deep dive to test the depthfinder system, profiling to within 77 meters of the bottom. Then, since the sled was not ready for deployment, another full depth HRP dive was done.

The injection sled was deployed for movement control and engineering systems tests on January 25 at 0000h. The sled was recovered six hours later to fix problems encountered during the tests. While the sled systems were being diagnosed and debugged, four more HRP dives (4–7) were completed, beginning a short transect at the bottom of the continental slope. The sled

was ready to go in the water again January 26 at 0200, so HRP operations were stopped and the sled was deployed. The next set of tests was successful, so the first tracer injection was started. Unfortunately, the orifices that disperse the tracer were not working correctly at the target pressure, so the injection was terminated early in order to get the sled back on deck to work on the problem. HRP dive 8 was completed while the sled was being overhauled. The sled went back in the water at 0300h January 26, and unfortunately, the pumps failed soon after the injection was started. The sled was recovered and HRP dive 9 was done at the injection site. Due to time constraints, the scientists decided to abandon this site and concentrate on getting the problems with the sled fixed during the transit to the second site, near the Mid-Atlantic Ridge.

At 1550h January 27, the *R/V Seward Johnson* got underway on the first section across the Brazil Basin. The transect progressed smoothly, with 16 more HRP dives (all to within 50 meters of the bottom), interspersed with 10 RAFOS float deployments. Consistently sunny, fair weather let this work proceed quickly and smoothly. At the end of the transect a total of 26 HRP profiles had been completed.

On February 3, the ship had reached 21°33′S, 18°5′W, a location in the eastern part of the basin, over the deep flanks of the Mid-Atlantic Ridge, the first where consistent deep mixing was observed. This site was chosen for the injection over the one originally proposed because the HRP showed little or no deep mixing there.

The first tracer injection run was started at 1800h February 3. Clogged orifices caused no tracer to be pumped, so the sled was recovered shortly after it reached its target depth of 4000 meters. A time series of HRP profiles was started next, and three dives (27–29) were completed before the injection sled was ready to go back in the water. After one false start, the sled was deployed and successfully injected SF6 to make the first streak on February 5. For the next week, a total of eight streaks of tracer was laid, with a RAFOS float deployed to sample and track each of the streaks. Two pop-up floats, programmed to surface in January 1997 and transmit their positions, were also deployed: one on February 8, just after streak 4; the other on February 11, during streak 7. The floats' positions in 1997 will determine where the tracer sampling is started. HRP profiles were done between tracer injection runs as time allowed: dives 31–44 were completed during the injections. These profiles continued the time series already mentioned, and started a survey across a small east-west trending ridge. The last tracer injection was completed at 1341h on February 12.

The next objective was to sample the tracer, to be sure it was injected where it was expected. Because the SF6 levels in the ocean are very low, any traces of it on the ship had to be removed before sampling was attempted. First, the injection sled was dismantled and its components were sealed in airtight wrappings and stored away. Then the ship was allowed to air for two days, permitting the SF6 to de-gas and decrease the potential for contamination. Finally, the sampling equipment was unpacked and the other sled assembled. During this process, between February 12 and 16, HRP profiles 45–61 were completed along a northeasterly track from the deployment site. Peaks and valleys along the flank of the Mid-Atlantic Ridge were extensively sampled by these profiles.

Having had a chance to de-gas, the ship returned to the tracer deployment site on February 16 at 2000h, when the first sampling run with blanks was done. Three sampling runs were completed over the next 5 days. Since the sampler takes 4 hours each for deployment and recovery, and collects water over an eight hour period, the ship is fully committed by towing the collecting sled for at least 16 hours/tow. One HRP dive was done between each sampling tow to occupy the time required to collect the water samples and turn the sled around. The tracer patch was sampled successfully, with the highest concentrations of SF6 observed at 4000 meters, where it had been injected.

On February 21, a final RAFOS float was deployed at the injection site, and the transit to Recife, Brazil was started. On the steam to port, ten HRP profiles (66–75) were completed, sampling across the Brazil Basin north of the track previously sampled. The *R/V Seward Johnson* arrived in Recife at 1130h on February 27, after 35 days at sea. A detailed listing of the HRP profiles made during the injection cruise is presented in Appendix 1.

Cruise Log – Sampling Cruise – Year 2

R/V Seward Johnson departed Recife, Brazil on March 13, 1997 at noon, in pouring rain steaming southeastward to the injection area. In order to maximize the time spent sampling, no repeat HRP section between Recife and the injection site was planned, so a 5 day transit was expected. Each day during the steam, a stop was made to test either the CTD or HRP. Various instrument, winch and communications related problems were detected and subsequently fixed. We arrived at the site of the first sampling station, west of the injection site on March 18, at 2000 GMT.

This trip had no weather heavy enough to suspend operations. Slightly stronger winds and heavier seas were experienced than on the previous cruise, but it was still basically fine weather throughout. Two swim calls provided pleasant diversions from the shipboard routine.

The work in the injection area was commenced with HRP profile 3 on March 18. The CTD system was not ready to go, so we steamed east and did another HRP profile. After that HRP profile was completed, the CTD was deployed. Several casts were required to have the bottles fire successfully. No tracer was found in these water samples. At the next station a CTD profile was made, but no bottles fired, so the HRP was deployed while more CTD repairs were made. When the HRP was recovered, another CTD profile was made, the bottles closed successfully, and SF6 was found in some of the samples! It was nice to find tracer so soon, verifying the analytic technique was working as expected.

We wanted to maximize the area sampled during the cruise, so our goal was to do a CTD and a HRP profile at each station and then get underway to the next station, as quickly as possible. The main constraint was having the CTD secured on deck early enough to allow the ship to position itself for recovering the HRP. For much of the cruise, this was the sequence of events: the CTD was deployed, finished the downcast, started the upcast, the bottles were fired and then the HRP was deployed. During the HRP's descent, the CTD was recovered, the water samples collected, and

then the ship was positioned to recover the HRP. The timing of operation required coordination between the groups and worked well after some initial changes.

The first survey line was planned to sample along the east-west trending valley that lies beneath the injection site. HRP profiles 3–27 (CTD's 3–27) were made on this line above the valley. HRP profile 12 was the closest to the injection site. Tracer was found much farther east than expected, and only decreased significantly after CTD 25.

The site where HRP and CTD 28 were deployed was offset from where it was planned to be, and, as a consequence, the water was 1500 meters shallower than expected. Unfortunately, as a result of the incorrect assumed bottom depth (the PDR bottom trace was hard to read), both the HRP and CTD hit bottom. Fortunately, neither instrument was badly damaged; the HRP was repaired before we arrived at the next station.

An excursion onto the Mid-Atlantic Ridge followed the initial sampling line in the valley. The first year's data suggested that deep mixing was enhanced in the eastern part of the basin over the rougher topography associated with the flanks of the Mid-Atlantic Ridge. The easternmost HRP profile last year was at 16°W, and we wanted to obtain profiles that would complete the section up to the Mid-Atlantic Ridge crest at about 11°30′W. HRP profiles 29–40 taken between March 26 and 28 comprise a loop onto the ridge and back to a position slightly south of the first line, from which the westbound sampling line was started. CTD profiles were not made in association with HRP profiles 29–40. The HRP acquired profiles over all sorts of bathymetric features during this side trip, and all showed high levels of turbulent mixing well into the water column, not just near the bottom.

Because no CTD's were done with the HRP profiles on the Mid-Atlantic Ridge, the numbers assigned to the HRP and CTD profiles were no longer the same. From HRP dive 41 until HRP dive 59, the number of the CTD cast associated with the HRP dive is (HRP dive # minus 11).

On March 28 at 1622h, CTD cast 30 was started, followed by HRP dive 41 to begin the next sampling leg. This leg went westward along an elevated ridge-like feature. The last station on this line was HRP dive 55, taken in the early morning of April 1.

Another eastward line, again in a valley, south of the first and second lines was then started. HRP dives (with concurrent CTD sampling) 56–65 comprise this line, which was finished on April 5. The traction head on the winch failed during CTD 48, causing near loss of the CTD package, but heroic efforts returned the CTD to the surface. Unfortunately HRP 59 had already been deployed when the failure occured. Since the CTD was still stuck at about 4500 meters when the HRP was due to surface, the ship's zodiac was used to return the HRP to the ship for recovery. It was determined that the winch was unrepairable, and that the CTD cable would have to be spooled onto the drum of the older, slower Markey winch. Operations were fully underway again 2 days later, after repairs and tests had been completed.

HRP dives 66–72 were taken on another more southerly westbound line, and HRP dives 73–80 were taken on the southernmost eastbound line. On these lines, ridges and valleys were sampled alternately. These stations took 5 days to finish with dive 80 completed on April 11. Tracer levels found in the water samples decreased to barely detectable levels as the ship progressed southward.

Since shiptime was running out, the decision to transit to a point north and east of the first line was made. This plan optimized the time left by finishing the last sampling in the direction of port.

The final sampling line was started late April 11, and was comprised of HRP dives 81–90. The steam back to Recife was started immediately following the last HRP profile, which was done with CTD 78 on April 14. We arrived at the dock as scheduled on April 18, after an extremely productive research cruise. A detailed listing of the HRP dives made during the sampling cruise is presented in Appendix 2.

HRP Instrument Description

The High Resolution Profiler (HRP) is an oceanographic instrument designed at WHOI to collect fine- and microstructure data during vertical profiles. A schematic of the HRP's structure and component systems is shown in Figure 3.

To minimize ship-induced noise in the measurements, the HRP dives without attachment to the ship. It is deployed, falls freely while collecting data (which it stores in 16 Mb of on-board RAM), drops its weights at a user-specified pressure, stops data acquisition, puts the computers in a wait state to conserve power, and rises to the ocean surface where it can be recovered. Once back on deck, the data are downloaded from instrument memory to a shipboard computer where analysis and archiving occur.

The HRP has two profiling modes: fine and micro, with the transition between them triggered by the CTD's pressure reaching user-defined threshold values. Fine sensors (including the CTD) are sampled at 10 Hz, and microstructure sensors are sampled at 200 Hz, with fine sampling continuing throughout the period of micro sampling.

Up to 16 sensors may be added to the HRP to complement the basic CTD measurements. The profiler is designed for versatility, so its configuration is determined by whichever suite of sensors is connected to the available channels. The configuration used for this experiment follows:

Fine Sensors	A/D Channel
pressure	–
temperature	–
conductivity	–
accelerometer top X	0
accelerometer top Y	1
accelerometer bottom X	2
accelerometer bottom Y	3
acoustic current meter X velocity	4
acoustic current meter Y velocity	5
X magnetometer	6
Y magnetometer	7
A/D ground	14

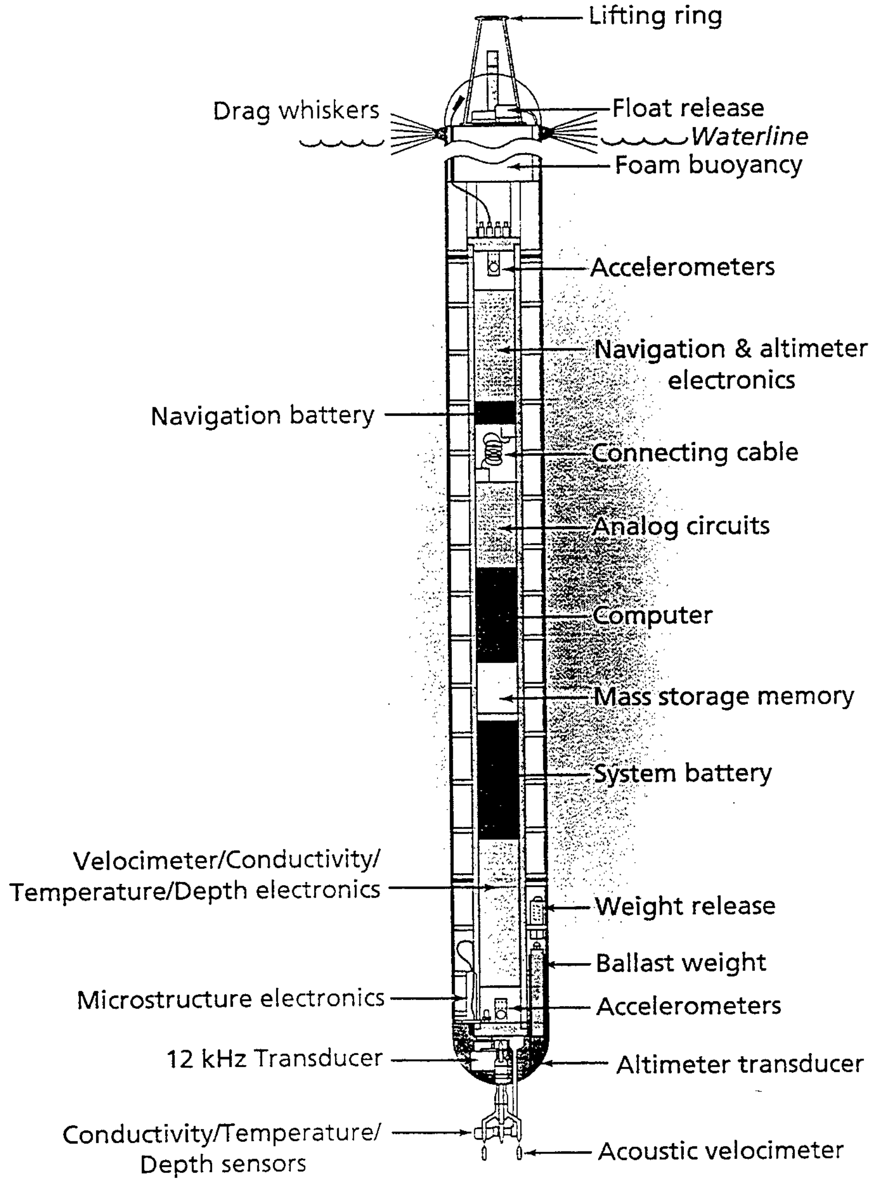


Figure 3: Cutaway view of the HRP component systems

Micro Sensors	A/D Channel
differential conductivity	10
differential temperature	11
shear X	12
shear Y	13

At a nominal descent rate of 0.6 meter/second, a 4000-meter dive takes 2 hours for descent, and 1 hour for ascent. During the dive, two megabytes of fine data and twelve megabytes of micro data will be acquired and stored, given the sensor configuration shown above. The transfer of data from the HRP is accomplished using a serial (RS232) connection operated at a nominal speed of 57.6 Kbaud. The actual speed obtained is about 45 Kbaud, which means it takes about an hour to transfer the data from the HRP to computers on the ship. Adding some time to maneuver during recovery, it takes 4 1/2 to 5 hours to complete a deep HRP profile.

To quantify the deep mixing accurately, close approaches to the bottom in areas of rough and rapidly changing bottom topography were required. Our experience with the Datasonics 900 altimeter that was interfaced to the HRP for the Abrupt Topography Experiment (TOPO) program (and used during the Circulation in the Romanche Fracture Zone Experiment (CIRFZ)) indicated the system would provide reliable ranges over flat seafloor, but perform less reliably over slopes. Prior to this cruise, software and hardware changes were incorporated and tested to allow the acoustic altimeter to function more robustly.

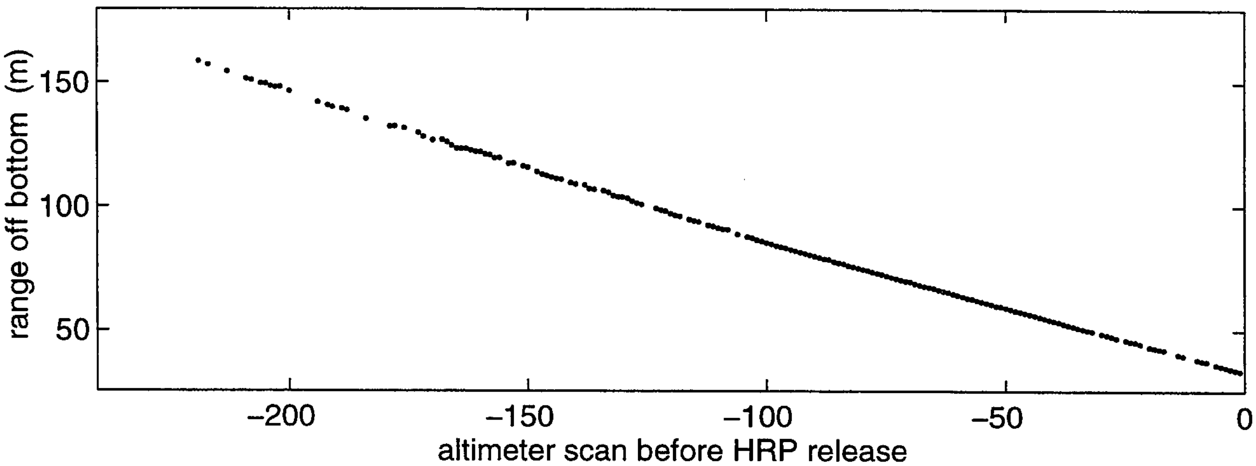
Often, the first good return occurred at about 150 meters from the bottom and ranges were received with little drop-out, however, other profiles lost as much as 50% of the expected altimeter data. Figure 4a shows all the altimeter data from the last 4 minutes of injection cruise's dive 31. Note the high rate of data return and that the furthest range detected was at 158.6 meters. An enlargement of the last 50 ranges is shown in Figure 4b, and shows occasional missing data, but generally good rates of return. Appendix 3 provides a list of how close to the bottom the HRP got on each profile during the injection cruise and which criterion caused dive termination.

During the second year cruise, there were only six incorrect dive terminations based on range. These were cases where a character in the range data stream was dropped, causing an early termination. Ninety-three percent of the profiles terminated correctly by either the range or pressure thresholds being met.

The HRP had several close calls with fate during this experiment. Early in the first cruise, the ship struck the profiler on recovery, gouging the protective skin. The damaged section was replaced immediately and the HRP was re-deployed. On the next dive, the profiler was again hit on recovery. This time it was brought on deck with only one of the four nuts that attach the floatation at the top of the instrument to the electronics case on the bottom still in place. Needless to say, all the nuts were replaced and carefully tightened before it went in the water again.

The HRP work continued uneventfully until dive 58, when part of one of the batteries that power the computer leaked and drained without the lowered capacity showing up in the pre-dive checks. The diminished power level allowed correct functioning on deck, but at cold temperatures

a.)



b.)

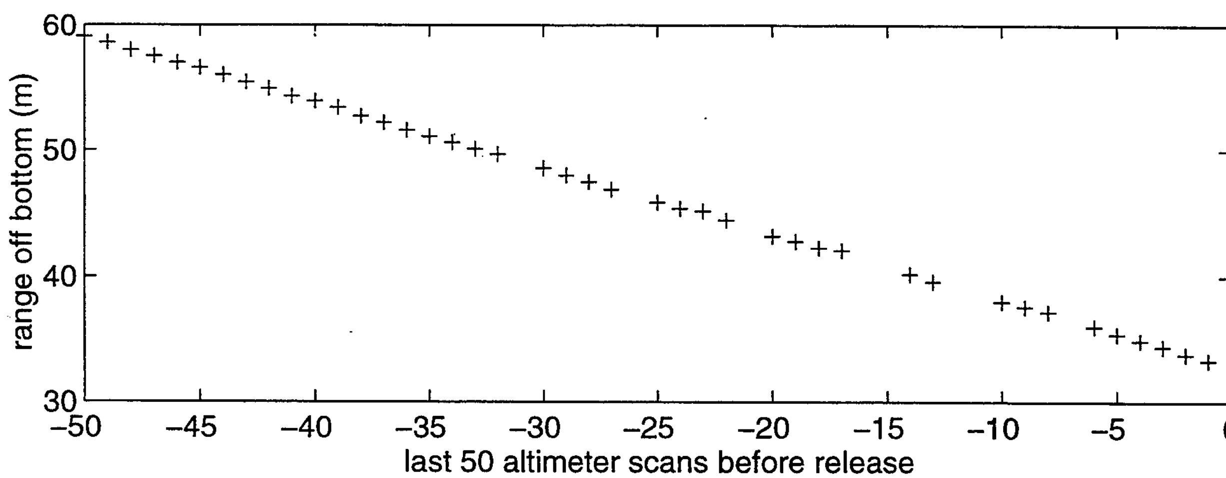


Figure 4: (a) altimeter data from the last 4 minutes of profile 31; (b) enlargement showing the last 50 altimeter returns.

encountered at depths greater than 4000 meters, the battery failed to run the release solenoids, causing the HRP to continue descending until it hit the bottom. Eventually the corrosible links broke and the HRP began to surface. No major structural damage occurred, but the microstructure probes all had to be replaced. The HRP hit the bottom twice more during the cruise, neither time causing significant damage: the first time it mysteriously failed to start logging, so consequently didn't have a way of knowing when to stop, and so went into the bottom; the second, a modification to the altimeter software had been downloaded but did not work as tested, causing a crash.

These incidents caused concern, but also showed the excellence of the original HRP design (kudos to the engineers involved!). Each time a problem caused a crash, one of the fail-safe release methods allowed the HRP to return to the surface, despite being stuck on the bottom for short durations. The shape, orientation and structure of the body and sensors have proved robust for the 5 cm/sec impacts encountered. So overall, the HRP has shown itself to be able to withstand the rigors of work in the deep sea.

For additional information on the development of the HRP, see the paper by Schmitt *et al.*, (1988; 1995) for operational details of working at sea with the HRP see the technical report by Montgomery (1991); and development of the altimeter interface is documented by Montgomery and Schmitt (1997).

Data Processing

The first step in the data processing is transferring the raw data acquired during a dive to a shipboard computer via a fast serial transfer. The rest of the processing is completed on UNIX workstations using programs developed especially for use with the HRP. As soon as the data are transferred to the PC, the altimeter data are converted to ascii and checked to determine the range from the bottom at weight release. Often the pressure criterion terminates a dive before the altimeter criterion is reached. The altimeter returns from these profiles are used to evaluate the altimeter's successful functioning in areas of rough topography.

The fine and micro data are stored as counts in binary format. The next step of the processing is converting the raw numbers to scientific units, applying some nominal calibrations, and making quality control (QC) plots. The quality control plots can indicate problems with any of the sensors that should be fixed before the next deployment. Examples of the fine and microstructure QC plots using profile 31 from year 1 are shown in Figures 5a–d.

As the QC plots are generated, a program is run that computes finescale velocity, plots potential temperature-salinity profiles, and bins the data in a uniformly incremented pressure series (typically 0.5 db). The velocity computation (Schmitt *et al.*, 1988) uses the acceleration and magnetometer data to correct the raw acoustic current meter data for instrument motion. Laboratory-derived calibration data are used to convert raw pressure and temperature data to scientific units. A laboratory-derived relationship is also utilized for the initial estimate of the conductivity cell calibration. Adjustments of this scale are subsequently derived to obtain consistent deep water potential temperature-salinity relationships. The output is stored in binary format while a plot of

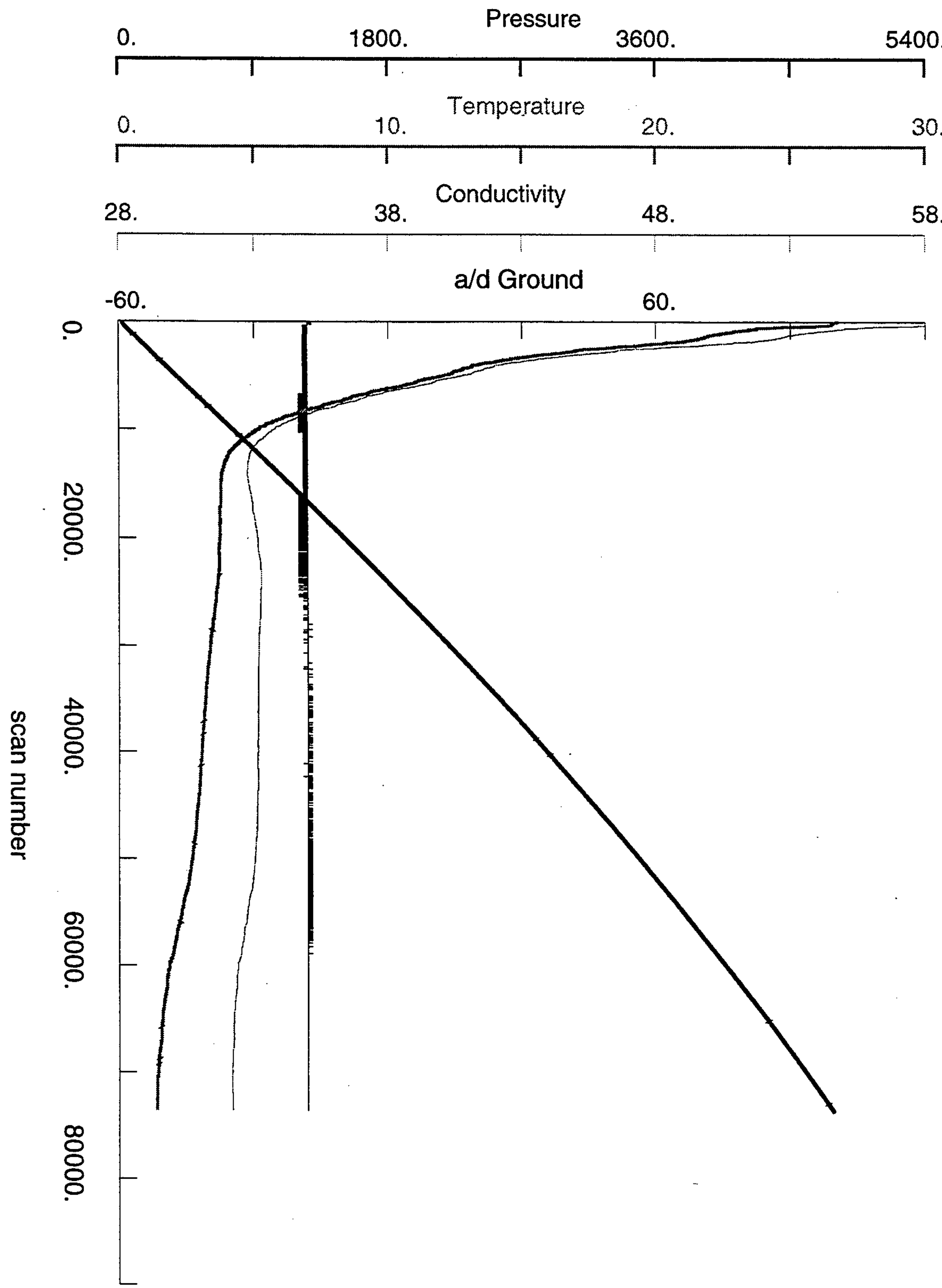


Figure 5: a. Finescale quality control plot of pressure, temperature, and conductivity for Profile 31.

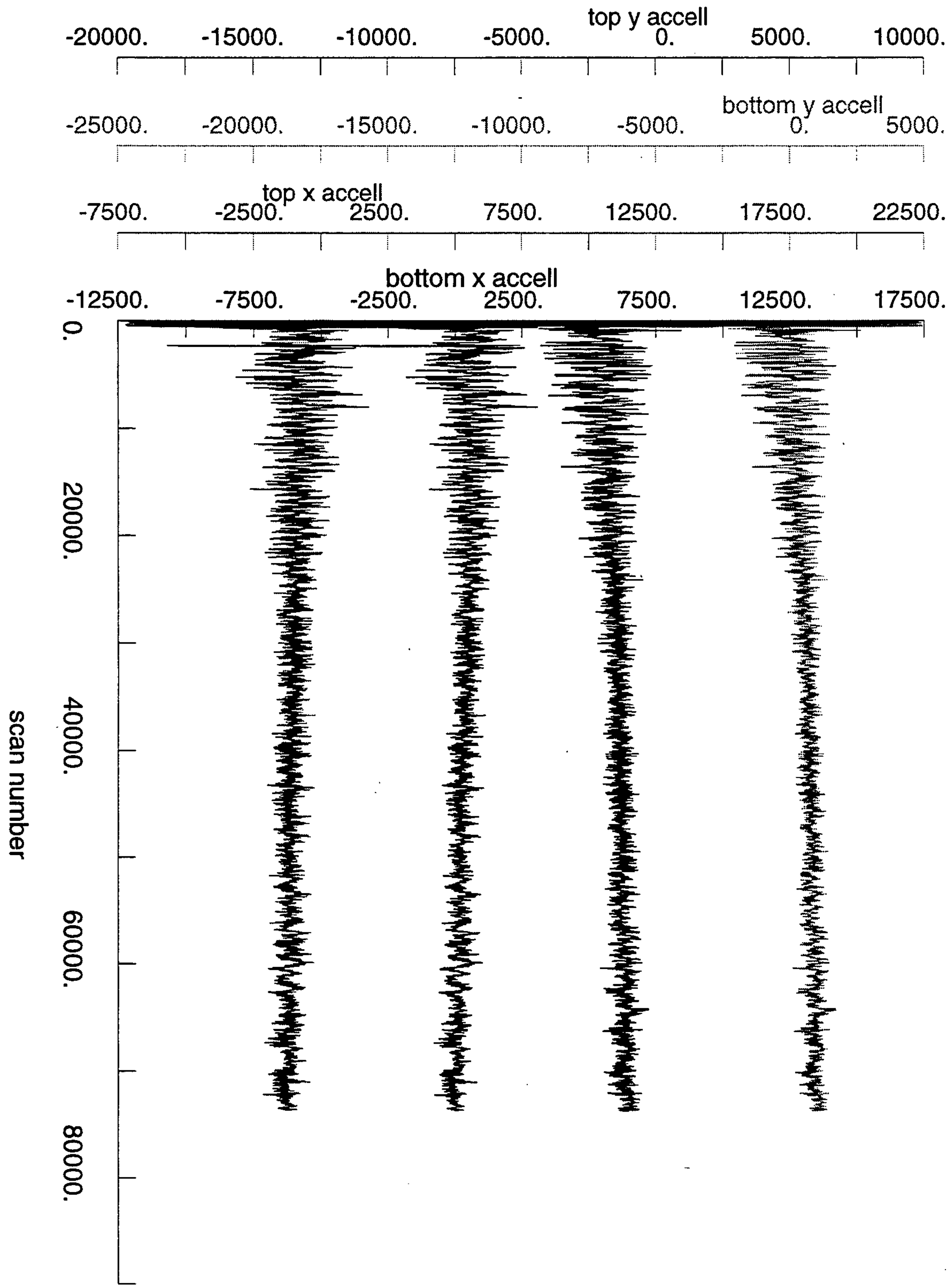


Figure 5: b. Finescale quality control plot of the two orthogonal accelerometer pairs for profile 31.

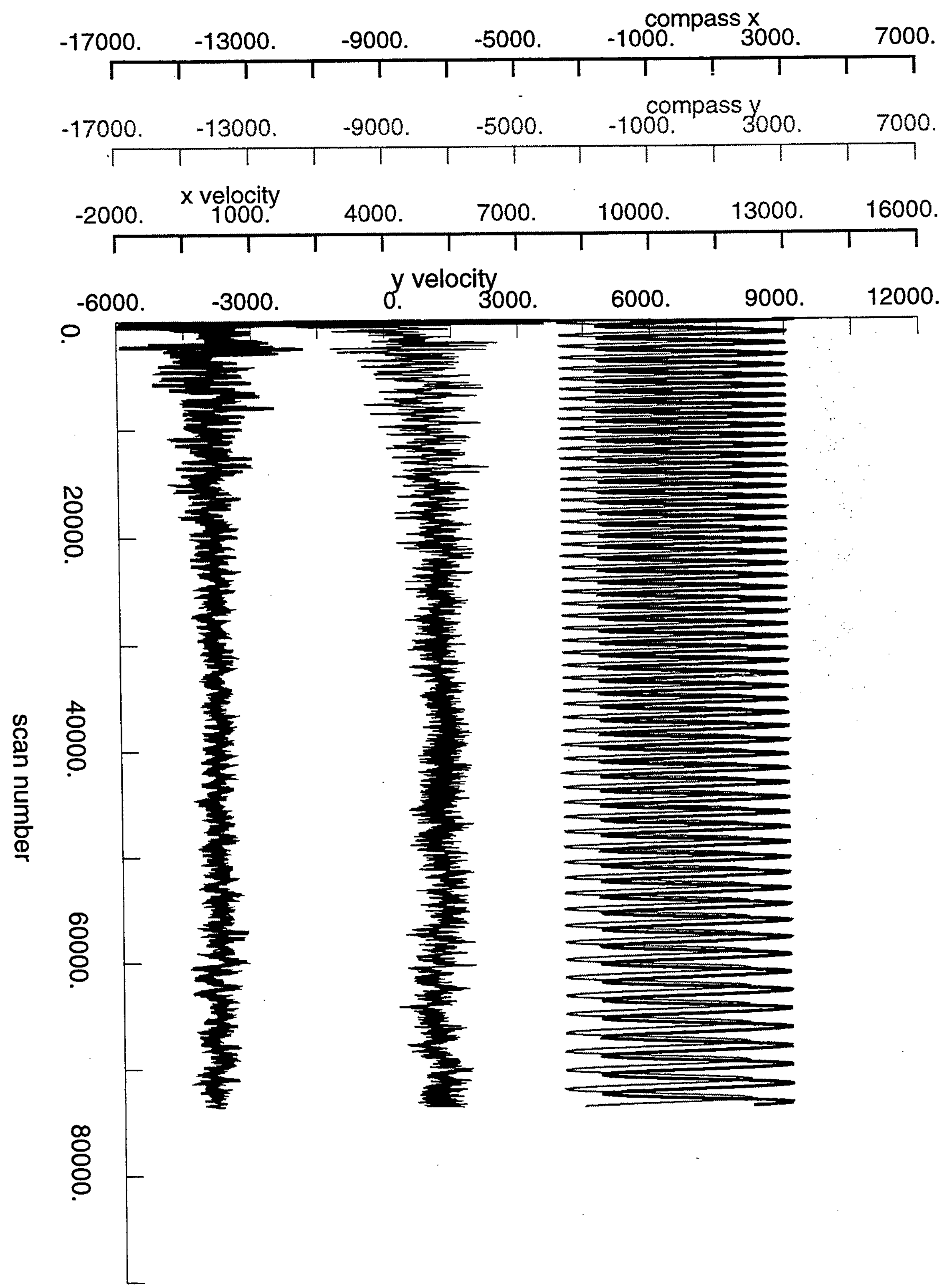


Figure 5: c. Finescale quality control plot of velocimeter and compass data from dive 31.

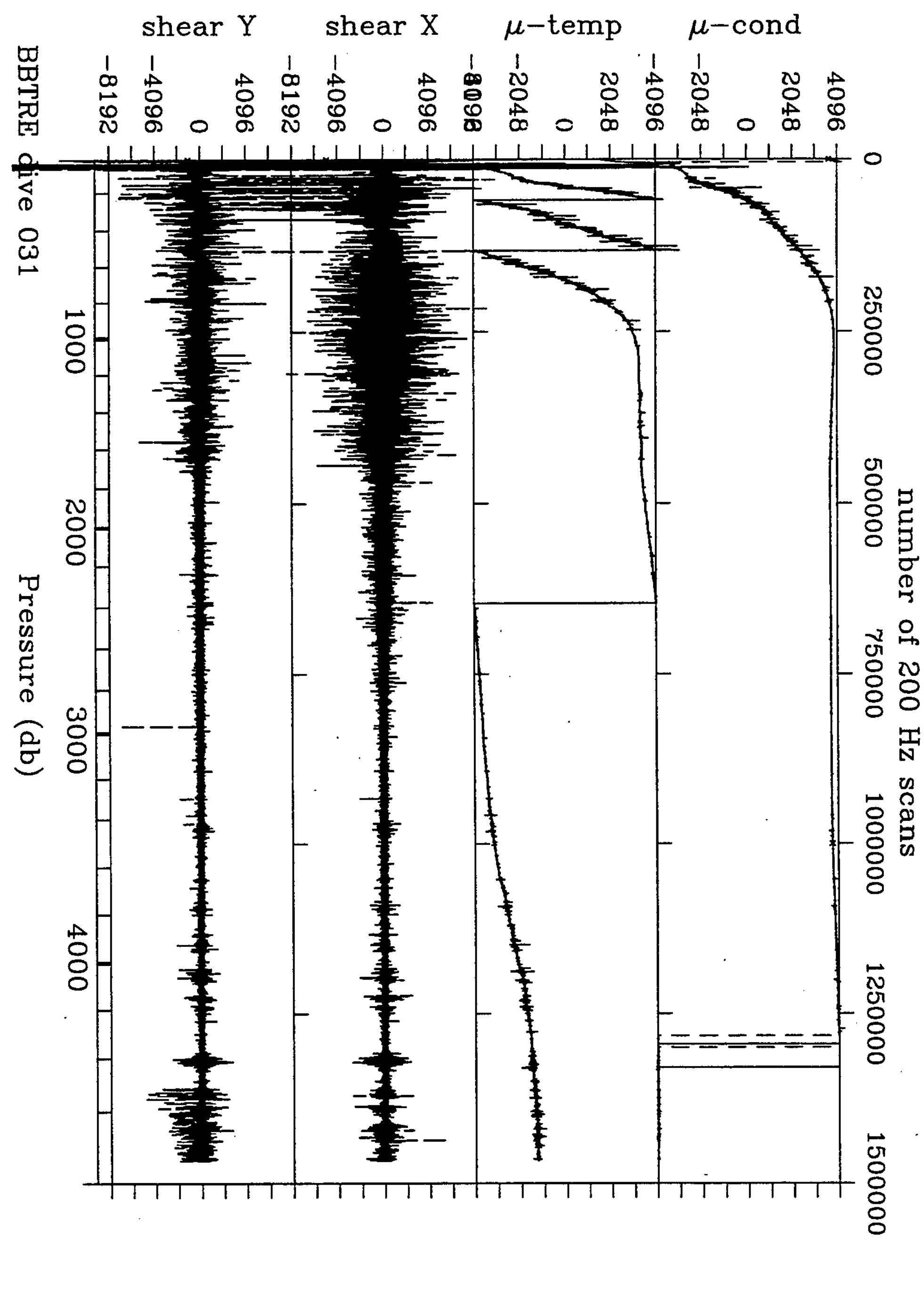


Figure 5: d. Microstructure quality control plot of differential temperature and conductivity, and shear for dive 31.

temperature, salinity, east and north velocities versus pressure is created. An example of this type of plot, again using profile 31 from year 1, is shown in Figure 6.

Microstructure data processing is started as soon as the data are transferred from the HRP but takes longer to complete, due to more densely sampled data and more computations performed. The scheme used follows procedures developed by Neil Oakey (Bedford Institute of Oceanography). A report by Polzin and Montgomery (1996) describes the microstructure data processing, so only a brief summary is included here.

The processing utilizes laboratory-derived calibration coefficients of the shear probes (microscale velocity sensors), while in-situ calibration data for the microscale temperature and conductivity sensors are obtained by reference to the finescale temperature and conductivity from the HRP. The microstructure data are binned in the time blocks aligned with the uniformly incrementing pressure series of the reduced finescale data. Gradient variances are estimated in the frequency domain after fast Fourier transforming by integrating spectra out to a local minimum in energy density. Spectral corrections are then applied for the finite responses of the sensors. After automated edit and consistency checking, scaling to scientific units yields estimates of the kinetic energy dissipation rate (ϵ, epsilon) and two measures of the dissipation rate of thermal variance (from the microscale temperature and conductivity sensors: chi-T and chi-C respectively). Profile plots (in "stick-diagram" form) of the dissipation rates are then produced, examples of which (again using profile 31, year 1) are shown in Figure 7.

The following is a short description of the enhancements made to the basic processing system during BBTRE. Three major software development feats were acomplished during this experiment. First, all the programs used for HRP processing were demonstrated to run (much faster) on the new SGI computers. Second, the functioning of these programs on the old DEC VAX computer and newer SGI ones was analyzed and the results compared. This allowed us to verify that the same program executed using the same data on each of the two machines produced the same results (within 0.05%). So now we can take only the SGIs to sea and be confident of the correctness of the results. Finally, and most fun, a Graphical User Interface (GUI) was developed for the suite of HRP processing programs by Tom Bolmer. Now, it is much easier to complete the data processing and generate the normal output.

Converting the HRP processing software to run on UNIX was fairly easy, but deciding where to prune antiquated files, formats and processes was more difficult. The "ctdvax" format and intermediate files of this type were eliminated during the port, and the format of the ".vel" file was changed, but routines were maintained or written to allow backward compatibility. The new programs on the SGIs have switches that allow the choice of input format.

The programs were also tested rigorously to verify that they work correctly. The numbers output by the programs and subroutines on the VAX were compared to those output by the SGIs to assure that no undetected errors were responsible for incorrect answers. The programs that work on the finescale data check out exactly, and the programs the accomplish the microstructure processing obtain very similar answers. The means of the final diffusivity estimates derived from the microstructure data differed by only 5e–12. We are confident that the programs now work robustly on the SGIs and generate answers that are statistically the same as those from the VAX.

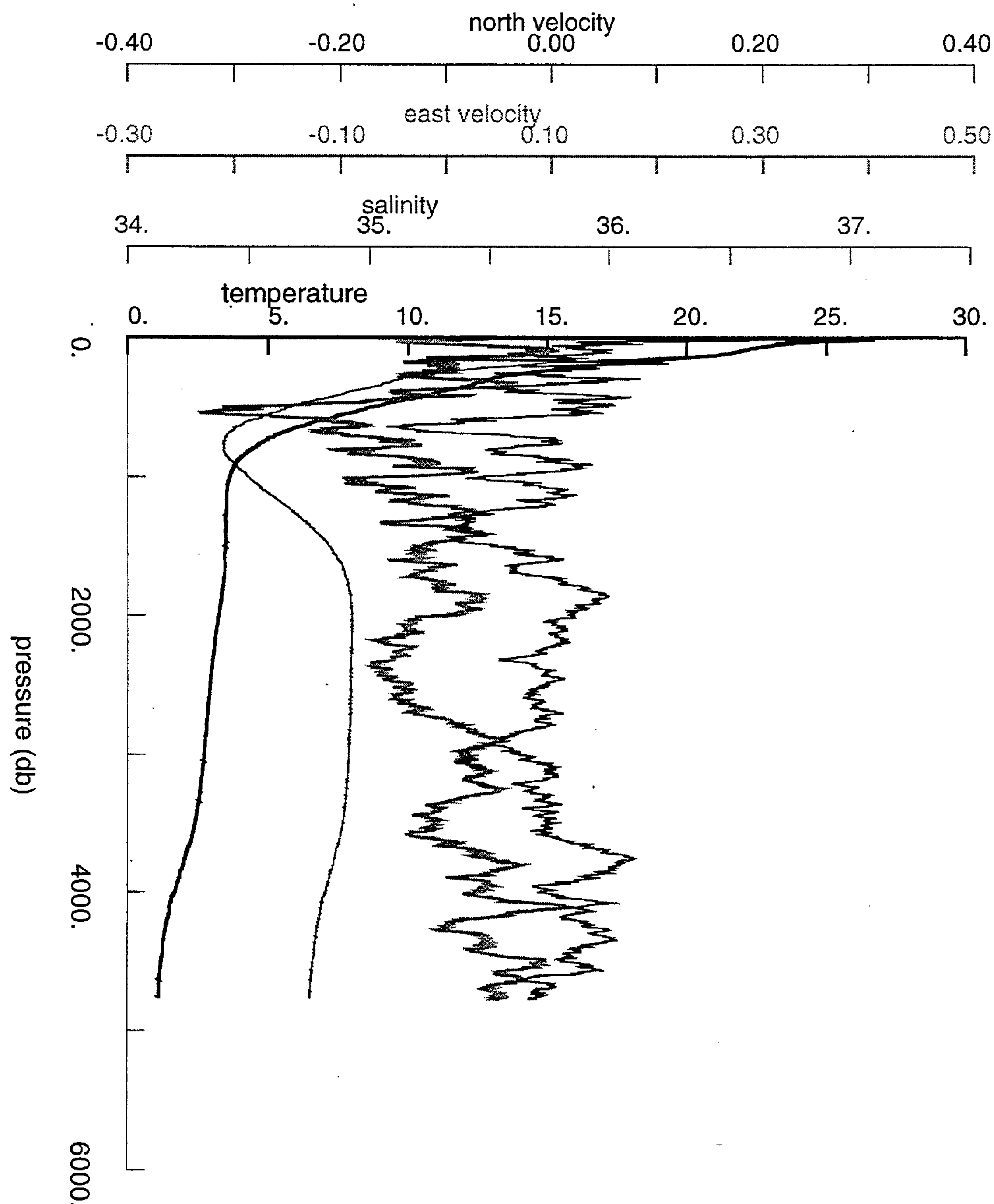


Figure 6: Sample velocity plot from dive 31.

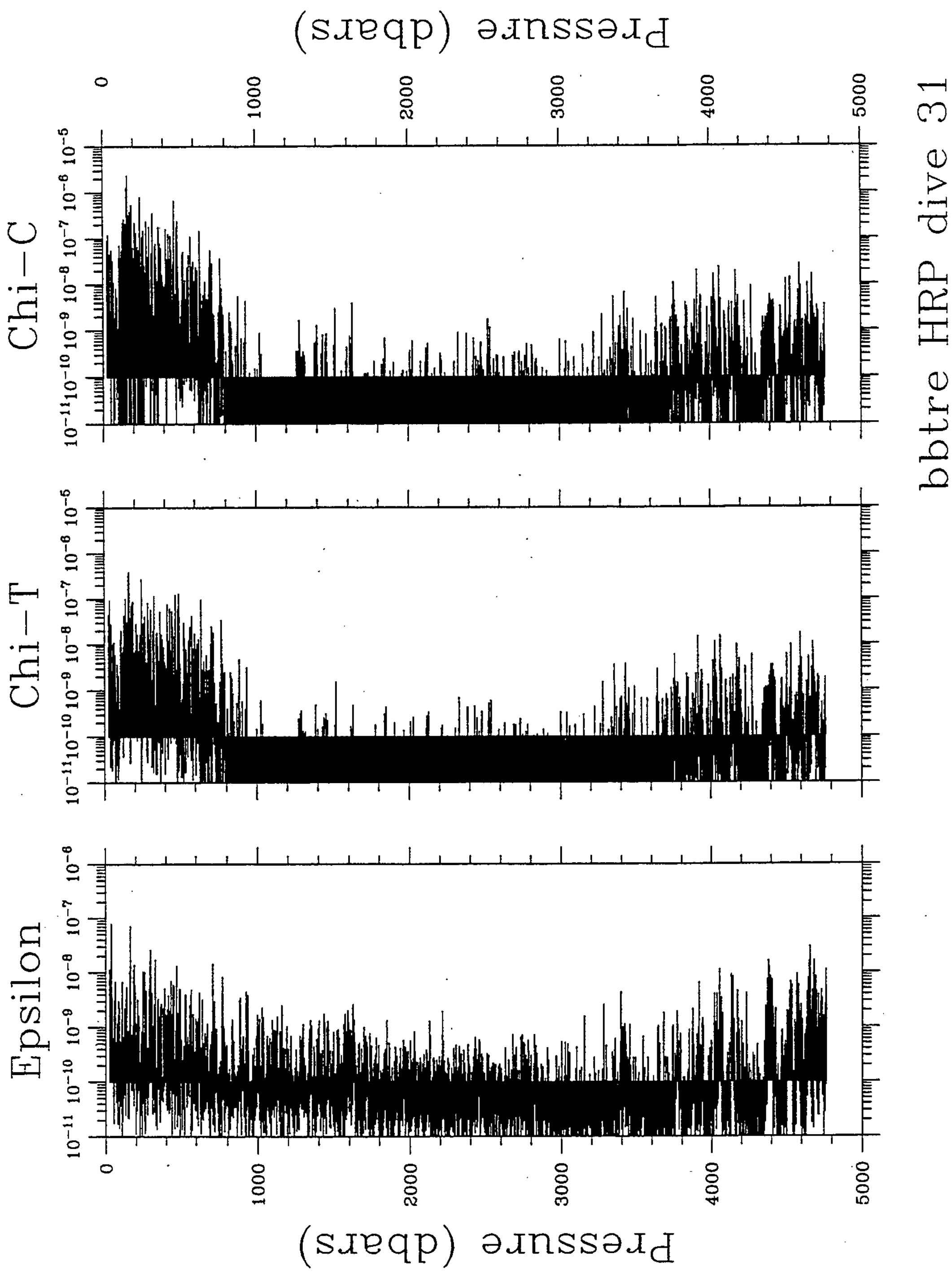


Figure 7: Stick plots epsilon, chi T and chi C.

Shell scripts to automate some of the processing steps replaced the equivalent VAX command files. These allow the operator to run several programs in sequence without doing the keyboard input by hand. The extension of writing the shell scripts to streamline the processing, was incorporating them into a Graphical User Interface (GUI) based system. The Tcl/Tk programming language was used to make the windows and call the processing scripts when the appropriate buttons are pressed. All the input needed for the programs can be entered in the GUI environment, and all the functions currently used in the at-sea HRP processing can be accessed. The UNIX processing system, the scripts used to automate running the programs and the GUI interface are documented in a report by Montgomery and Bolmer (in preparation).

Results

Both the Tracer and HRP groups felt this was a very successful experimental program. We worked well together utilizing the available shiptime to the fullest. During the first cruise approximately 114 kg of tracer was applied at a depth of 4010 meters in order to have initial concentrations of 0.04 M detected during the post-injection sampling runs. In 75 dives, the HRP was able to complete two cross-basin surveys, identify a site with active mixing at which to deploy the tracer, and sample ridge and valley areas of the flanks of the Mid-Atlantic Ridge.

During the second cruise, the tracer distribution was mapped and found to be spread over an area of 250,000 km^2. To within the detection limits of the sampling method, all the tracer deployed was accounted for in the second year's sampling. The 90 HRP dives completed provide instantaneous estimates of diffusivity and dissipation to compare with the estimates based on the tracer distributions. The estimates from the two methods agree quite well.

The cross-basin sections, acquired by the HRP during the injection cruise and extended during the sampling cruise, have made us rethink how deep mixing works. Fairly constant levels of mixing were expected across the basin, with enhanced mixing occurring near the bottom. In actuality, the two HRP transects showed the part of the Brazil Basin west of 28°W to have very low levels of mixing ($K\rho < 1e-5$), and the eastern part to have much higher levels. As shown in Figure 8, there appears to be correlation between topographic roughness in the eastern basin and elevated levels of turbulent diffusivity. The highest levels of $K\rho$ are found near the bottom, but mixing is enhanced well into the mid-water. The papers by Polzin *et al.* (1997) and Toole *et al.* (1997) document the scientific results in greater detail than is presented here.

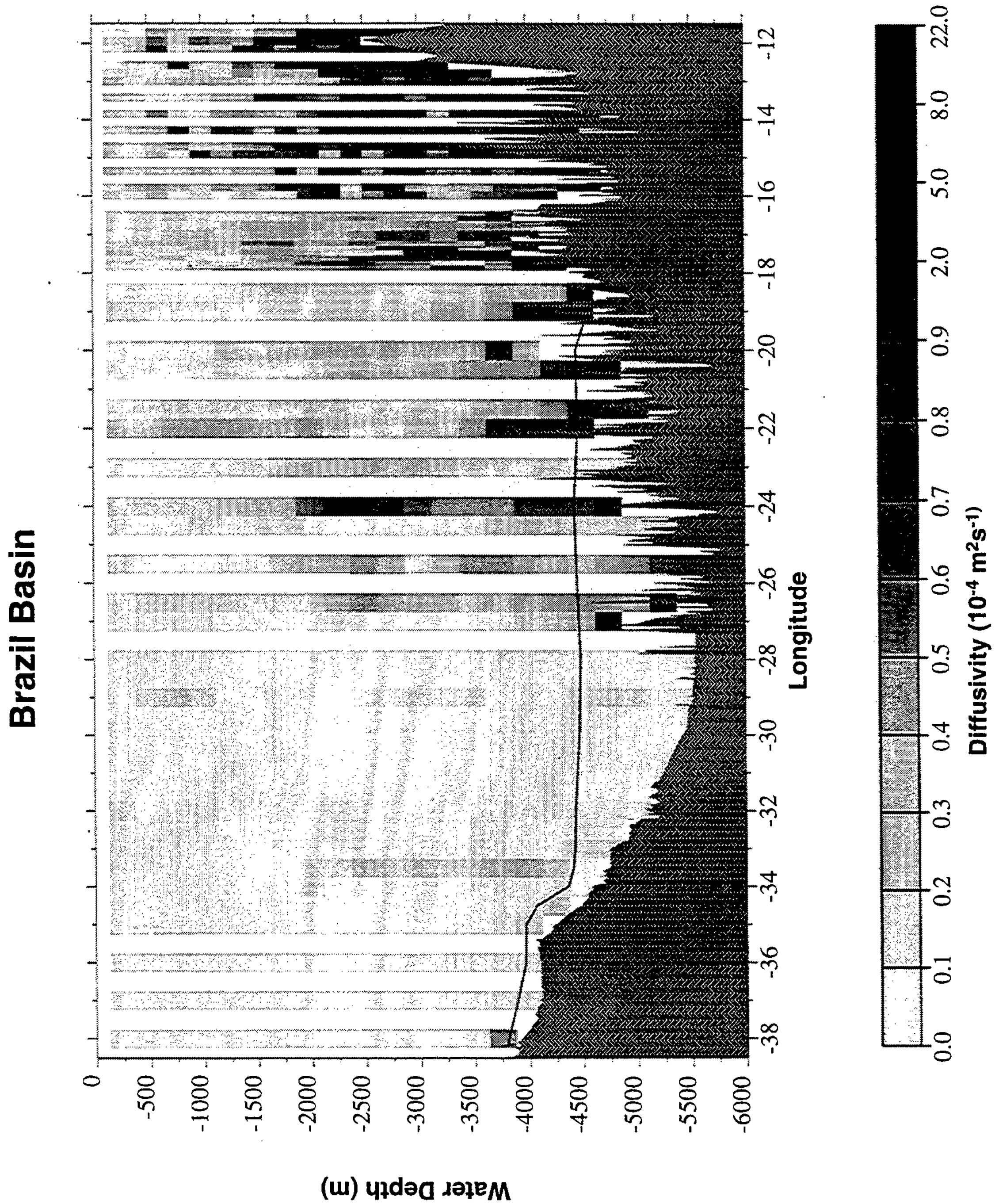


Figure 8: Contours of K_ρ from the two cross-basin HRP sections.

Appendix 1

HRP Deployment Positions for the Brazil Basin Tracer Release Experiment
Injection Cruise: Year 1

Dive #	Date m/d/y	Time GMT	Deployment Latitude (South &		Longitude West)		Pmax (db)	Range from Bottom	Comments
01	01/24/96	0759	24	58.83	38	32.11	1000	–	test dive 1
02	01/24/96	1237	25	00.12	38	11.12	3917	77.8	test dive 2
03	01/24/96	1951	25	00.17	38	11.09	3962	30.0	base of continental
04	01/25/96	0642	25	00.08	38	11.13	3962	29.7	slope
05	01/25/96	1235	25	00.04	38	11.15	3976	15.0	"
06	01/25/96	1710	24	52.01	38	25.12	3907	21.2	"
07	01/25/96	2240	25	05.80	38	01.09	3997	24.4	"
08	01/26/96	2122	25	00.19	38	11.00	3982	15.0	"
09	01/27/96	1130	25	00.03	38	10.98	3980	15.0	begin S. transect
10	01/27/96	2210	24	44.87	36	58.74	4166	22.2	continue transect
011	01/28/96	0606	24	30.09	35	59.75	4164	14.7	"
012	01/28/96	1351	24	29.89	34	59.90	4234	70.2	"
013	01/28/96	1917	24	30.13	34	29.95	4515	34.9	"
014	01/29/96	0059	24	30.07	33	59.50	2965	–	"
015	01/29/96	0644	24	29.98	33	29.73	4780	53.3	"
016	01/29/96	1234	24	29.94	32	59.83	4820	23.2	"
017	01/29/96	1837	24	29.96	32	29.92	5020	40.8	"
018	01/30/96	0034	24	29.99	32	00.00	5151	66.9	"
019	01/30/96	1326	24	09.96	30	06.90	5362	94.0	"
020	01/31/96	1040	23	52.94	28	19.42	5338	–	"
021	01/31/96	2326	23	38.97	26	31.79	5425	40.8	"
022	02/01/96	1527	23	15.89	24	03.87	4830	52.4	"
023	02/02/96	0112	22	49.94	22	53.27	5387	–	"
024	02/02/96	1053	22	18.86	21	58.37	5110	–	"
025	02/03/96	0041	21	55.99	20	07.97	5015	–	"
026	02/03/96	1342	21	35.18	18	29.95	4659	77.6	begin 18.5°W series
027	02/04/96	0214	21	41.32	18	30.21	5260	66.7	continue series
028	02/04/96	0719	21	35.68	18	30.04	4634	91.2	"
029	02/04/96	1731	21	32.52	18	29.79	4348	15.0	"
030	02/04/96	2049	21	32.17	18	30.01	4400	45.1	"
	02/05/96	1637							1st tracer injection
031	02/06/96	1410	21	37.95	18	29.98	4786	33.3	"
032	02/07/96	0931	21	32.43	18	29.67	4400	42.6	"
033	02/07/96	1331	21	24.69	18	29.98	4817	–	
	02/08/96	0732	21	40.58	18	23.06			Pop-up #2 deployed

(Continued) HRP Deployment Positions for the Brazil Basin Tracer Release Experiment

Injection Cruise: Year 1

Dive #	Date m/d/y	Time GMT	Deployment Latitude (South		& Longitude	West)	Pmax (db)	Range from Bottom	Comments
034	02/08/96	0832	21	35.00	18	29.87	4670	43.1	"
035	02/08/96	1319	21	28.72	18	29.98	4606	65.2	"
036	02/09/96	0341	21	40.97	18	30.02	5080	101.8	"
037	02/09/96	0824	21	32.42	18	30.07	4440	59.2	"
038	02/09/96	1251	21	32.52	18	32.96	4346	76.1	"
039	02/09/96	1634	21	37.91	18	29.92	4803	15.0	"
040	02/09/96	2045	21	28.88	18	30.11	4502	15.0	"
041	02/10/96	1603	21	24.60	18	29.99	4813	15.0	"
042	02/11/96	0100	21	32.32	18	30.14	4365	75.4	"
043	02/11/96	0455	21	35.04	18	30.15	4681	14.7	"
	02/11/96	2126	21	41.12	18	27.58			Pop-up #1 deployed
044	02/12/96	0104	21	41.04	18	30.08	5120	–	start Mid-Atlantic Ridge
	02/12/96	1341							profiles tracer injections
045	02/12/96	2340	21	20.04	17	49.24	–	–	complete continue
046	02/13/96	0640	21	25.21	17	51.41	1000	–	near MAR
047	02/13/96	0816	21	19.89	17	49.39	4238	15.0	"
048	02/13/96	1258	21	18.36	17	42.15	4354	14.8	"
049	02/13/96	1701	21	17.75	17	36.08	4183	29.1	"
050	02/13/96	2121	21	15.92	17	25.09	3897	37.4	"
051	02/14/96	0134	21	14.94	17	19.09	4553	14.6	"
052	02/14/96	0546	21	14.12	17	14.84	3977	41.4	"
053	02/14/96	0916	21	13.60	17	11.34	4491	14.8	"
054	02/14/96	1336	21	12.09	17	92.91	3845	30.8	"
055	02/14/96	1936	21	07.83	16	36.47	4598	14.8	"
056	02/14/96	0012	21	07.06	16	31.30	4000	16.8	"
057	02/15/96	0436	21	05.90	16	23.80	4472	14.1	"
058	02/15/96	1006	21	05.54	16	32.09	3892	0.00	"
059	02/16/96	0241	21	17.10	17	32.09	4000	–	"
060	02/16/96	0714	21	17.14	17	32.02	4353	15.4	"
061	02/16/96	1155	21	18.64	17	40.18	4601	14.6	"
062	02/17/96	1641	21	41.33	18	30.11	5305	16.0	resample at 18.5W
063	02/18/96	0023	21	32.33	18	30.06	4320	14.9	"
064	02/19/96	0821	21	37.97	18	30.12	4727	112.7	"
065	02/20/96	1239	21	59.88	18	29.82	4603	39.8	"
066	02/21/96	2356	19	47.96	20	14.05	4237	–	begin N. transect
067	02/22/96	1607	17	59.99	22	05.06	4628	0.00	continue section
068	02/23/96	0931	16	08.45	24	04.42	5518	14.6	"

(Continued) HRP Deployment Positions for the Brazil Basin Tracer Release Experiment 1

Injection Cruise: Year 1

Dive #	Date m/d/y	Time GMT	Deployment Latitude (South &		Longitude West)		Pmax (db)	Range from Bottom	Comments
069	02/23/96	2248	14	57.00	25	35.00	5608	–	"
070	02/24/96	1232	13	40.02	27	05.08	4876	46.4	"
071	02/24/96	2220	12	53.90	28	07.06	5651	14.8	"
072	02/25/96	0807	12	16.88	29	07.22	5623	14.3	"
073	02/25/96	1749	11	24.09	29	59.92	5517	14.9	"
074	02/26/96	0206	11	00.05	30	48.87	5370	14.7	"
075	02/26/96	1122	10	26.77	31	46.16	5316	22.3	"

Appendix 2

HRP Deployment Positions for the Brazil Basin Tracer Release Experiment

Sampling Cruise: Year 2

Dive #	Date m/d/y	Time GMT	Deployment Latitude (South		& Longitude West)		Pmax (db)	Range from Bottom	Comments
001	03/15/97	1611	13	18.55	30	22.89	1000	−99	test dive to 1000 meters
002	03/16/97	1514	16	19.23	27	39.47	5159	−99	test dive to full depth
	03/17/97	1500	19	02.49					wire tangle on winch take-up spool
003	03/18/97	2052	21	55.35	22	18.60	5415	−99	1st dive in tracer area
004	03/19/97	0531	21	55.02	21	23.35	5323	92.9	eastbound canyon line
005	03/19/97	2058	21	52.77	20	50.67	5383	78.0	"
006	03/20/97	0911	21	50.89	20	29.66	5434	57.4	"
007	03/20/97	1707	21	48.92	20	08.38	5407	29.9	"
008	03/21/97	0143	21	45.74	19	45.08	5105	24.8	"
009	03/21/97	0943	21	45.98	19	24.68	5267	25.0	"
010	03/21/97	1826	21	44.93	18	53.18	5310	24.7	"
011	03/22/97	0015	21	44.00	18	33.50	−99	−99	"
012	03/22/97	0238	21	43.96	18	33.48	5198	115.0	(nearest to injection site)
013	03/22/97	0954	21	40.11	18	10.86	5358	9.6	continuing east
014	03/22/97	1651	21	36.27	17	48.40	5175	9.8	"
015	03/22/97	2305	21	36.97	17	25.09	4848	24.9	"
016	03/23/97	0530	21	30.59	17	04.93	5237	14.3	"
017	03/23/97	1207	21	27.86	16	43.04	5250	81.5	"
018	03/23/97	1935	21	22.97	16	22.79	4863	19.7	"
019	03/24/97	0054	21	20.91	16	00.94	4995	19.5	"
020	03/24/97	0855	21	16.23	15	37.99	4763	20.0	"
021	03/24/97	1442	21	14.96	15	17.61	4779	14.5	"
022	03/24/97	2107	21	08.90	14	54.39	4977	23.2	"
023	03/25/97	0318	21	03.84	14	30.64	4717	40.2	"
024	03/25/97	0947	21	00.56	14	09.63	4989	14.3	"
025	03/25/97	1605	20	55.17	13	43.71	4576	14.8	"
026	03/25/97	2216	20	47.00	13	17.47	4633	18.7	"
027	03/26/97	0344	20	42.37	12	58.68	4483	19.9	"
028	03/26/97	0915	20	48.53	12	37.45	3207	0.0	crash on flank of MAR
029	03/26/97	1652	20	26.03	12	35.35	3842	19.4	Mid-Atlantic Ridge loop
030	03/26/97	2115	20	25.07	12	17.38	3535	−99	(no CTD's)
031	03/27/97	0123	20	24.07	12	00.33	2252	−99	"
032	03/27/97	0441	20	35.27	11	49.89	1893	−99	"
033	03/27/97	0758	20	39.98	11	33.69	3044	−99	"

(Continued) HRP Deployment Positions for the Brazil Basin Tracer Release Experiment

Sampling Cruise: Year 2

Dive #	Date m/d/y	Time GMT	Deployment Latitude (South		& Longitude	West)	Pmax db	Range from Bottom	Comments
034	03/27/97	1139	20	50.08	11	48.90	2471	−99	"
035	03/27/97	1442	21	03.08	11	48.87	2266	85.8	"
036	03/27/97	1808	21	12.13	12	08.01	3170	19.8	"
037	03/27/97	2208	21	17.17	12	27.84	3096	19.6	"
038	03/28/97	0204	21	20.30	12	47.83	3600	89.6	"
039	03/28/97	0630	21	20.14	13	07.93	3544	14.5	"
040	03/28/97	1040	21	19.95	13	28.11	3196	101.5	"
041	03/28/97	1637	21	29.17	14	09.42	4432	14.8	southern westbound track along ridge
042	03/28/97	2317	21	35.13	14	46.13	4167	42.1	"
043	03/29/97	0531	21	46.65	15	21.67	4579	14.8	"
044	03/29/97	1135	21	48.62	15	54.86	4174	18.7	"
045	03/29/97	1647	21	52.90	16	21.49	4489	−99	"
046	03/29/97	2215	21	56.49	16	46.82	4267	24.9	"
047	03/30/97	0401	21	59.97	17	16.09	4560	24.4	"
048	03/30/97	0937	22	04.02	17	42.92	4445	15.0	"
049	03/30/97	1503	22	07.73	18	09.87	4694	14.7	"
050	03/30/97	2043	22	11.09	18	36.06	4843	71.9	"
051	03/31/97	0211	22	08.39	19	02.92	4816	32.0	"
052	03/31/97	0801	22	15.02	19	29.54	5103	48.0	"
053	03/31/97	1432	22	17.90	20	06.81	5037	15.0	"
054	03/31/97	2146	22	21.01	20	51.99	5217	44.0	"
055	04/01/97	0355	22	32.12	21	17.90	5288	21.0	"
056	04/01/97	1059	23	06.06	21	07.89	5068	15.0	more southerly eastbound line
057	04/01/97	1858	22	54.97	20	31.41	4748	34.0	(in valley)
058	04/02/97	0133	22	52.64	19	52.67	4673	93.1	"
	04/02/97	0805	22	51.13	19	12.76			traction head failed during CTD #48
059	04/02/97	0811	22	50.91	19	12.86	4030	7.5	"
060	04/03/97	0410	22	48.87	18	33.69	4754	19.3	"
061	04/03/97	0909	22	48.86	18	33.96	4785	48.3	"
062	04/04/97	1013	22	42.08	17	52.73	4648	14.6	"
063	04/04/97	1842	22	38.82	17	12.15	4494	126.5	"
064	04/05/97	0311	22	16.74	16	35.32	4722	99.0	"
065	04/05/97	1104	22	13.53	15	52.00	4361	14.9	"
066	04/05/97	1827	22	49.60	15	51.87	4339	22.3	more southerly

(Continued) HRP Deployment Positons for the Brazil Basin Tracer Release Experiment

Sampling Cruise: Year 2

Dive #	Date m/d/y	Time GMT	Deployment Latitude (South		& Longitude West)		Pmax db	Range from Bottom	Comments
									westbound line
067	04/06/97	0223	22	54.86	16	33.63	4669	19.7	"
068	04/06/97	1110	23	07.82	17	30.96	4930	−99	"
069	04/06/97	1944	23	26.45	18	23.88	4528	68.0	"
070	04/07/97	0351	23	20.27	19	19.44	4890	113.0	"
071	04/07/97	1201	23	41.52	20	09.14	4706	15.0	"
072	04/07/97	2357	23	50.32	20	59.35	5341	−99	"
073	04/08/97	0956	24	24.59	20	11.35	4685	45.8	most southerly line, eastbound
074	04/08/97	1745	24	56.54	20	43.38	4970	19.7	"
075	04/09/97	0205	24	48.23	19	47.80	5318	58.7	"
076	04/09/97	1020	24	08.67	19	20.14	4841	14.4	"
077	04/09/97	1929	24	08.52	18	20.62	4509	119.6	"
078	04/10/97	0754	23	23.83	16	48.91	4756	76.8	"
079	04/10/97	1658	23	10.45	15	52.59	5014	14.8	"
080	04/11/97	0142	22	59.76	14	59.35	4882	105.3	"
081	04/11/97	1758	20	48.51	15	51.88	4596	−99	westbound line,
082	04/12/97	0222	20	47.27	16	46.48	5163	68.1	north of original valley line
083	04/12/97	1035	20	21.01	17	30.39	4468	70.8	"
084	04/12/97	1719	20	54.81	17	51.09	5268	60.1	"
085	04/13/97	0042	20	54.81	17	51.15	5303	81.1	"
086	04/13/97	0914	20	56.71	18	41.20	4710	14.9	"
087	04/13/97	1631	21	11.14	19	28.45	5171	14.8	"
088	04/13/97	2316	20	43.50	19	39.94	4656	177.8	"
089	04/14/97	0938	20	58.12	20	30.40	4696	74.6	"
090	04/14/97	1521	20	23.47	21	12.14	5327	47.9	last station

Appendix 3

Range From Bottom at Dive End During BBTRE 1

Dive #	Cause of Release	Target Range	Range from Bottom	Pmax of Dive
Release Key: P = pressure, R = range, T = time, N = none				
001	P	–	–	1000.0
002	P	300	77.8	3917.0
003	R	300	30.0	3962.3
004	R	300	30.0	3962.4
005	R	150	15.0	3975.7
006	P	150	21.2	3907.1
007	P	150	24.4	3997.0
008	P	150	15.8	3982.1
009	R	150	16.6 ?	3979.6
010	P	150	21.0	4166.1
011	R	150	14.7	4164.5
012	R (wrong!)	150	70.2	4234.4
013	P	150	34.9	4514.8
014	T	150	?	2964.6
015	P	100	53.3	4779.7
016	P	100	23.2	4819.8
017	P	150	40.8	5020.0
018	P	150	66.9	5150.8
019	T	200	94.0	5361.6
020	T	150	~150	5338.4
021	P	150	40.8	5425.2
022	P	150	52.4	4830.4
023	T	150	? >150 ?	5387.0
024	P	150	? >150 ?	5110.2
025	P	150	? >150 ?	5015.4
026	P	150	77.6	4658.9
027	P	150	66.7	5259.8
028	R (wrong!)	150	91.2	4634.1
029	R	150	15.0	4347.6
030	P	150	45.1	4400.2
031	P	150	33.3	4785.5
032	P	150	42.6	4400.0
033	P	150	? >150 ?	4816.0
034	R (wrong!)	150	43.1	4669.5
035	P	150	65.2	4605.9

Range From Bottom at Dive End During BBTRE 1
(Continued)

Dive #	Cause of Release	Target Range	Range from Bottom	Pmax of Dive
Release Key: P = pressure, R = range, T = time, N = none				
036	P	150	101.8	5080.0
037	P	150	59.2	4440.0
038	P	150	76.1	4346.0
039	R	150	14.9	4803.0
040	R	150	15.0	4501.8
041	R	150	14.7	4813.2
042	R (wrong!)	150	74.8	4365.4
043	R	150	14.7	4680.5
044	P	150	? >150 ?	5120
045 (crash)	N	150	–	–
046	P	–	–	1000.0
047	R	150	15.0	4238.3
048	R	150	14.8	4354.5
049	P	150	29.1	4103.3
050	P	150	37.4	3897.3
051	R	150	14.6	4553.0
052	P	150	41.4	3977.3
053	R	150	14.8	4491.4
054	P	150	30.8	3845.2
055	R	150	14.8	4598.1
056	P	150	16.8	4000.0
057	R	150	14.1	4471.5
058 (crash)	P	150	? >150 ?	3892.3
059	P	150	? >150 ?	4000.2
060	R (wrong!)	150	96.1	4352.6
061	R	150	14.6	4601.0
062	P	150	16.0	5305.2
063	R	150	14.9	4320.0
064	R (wrong!)	150	111.0	4726.6
065	P	150	39.8	4601.3
066	P	150	? >150 ?	4237.1
067 (crash)	P	150	1.4	4628.1
068	R	150	14.6	5517.6
069	P	150	75.6	5608.1
070	P	150	46.4	4876.4
071	R	150	14.8	5605.7

Range From Bottom at Dive End During BBTRE 1
(Continued)

Dive #	Cause of Release	Target Range	Range from Bottom	Pmax of Dive
Release Key: P = pressure, R = range, T = time, N = none				
072	R	150	14.3	5623.2
073	R	150	14.9	5516.8
074	R	150	14.7	5370.3
075	P	150	22.3	5315.5

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16. Abstract (Limit: 200 words)

On two recent cruises (January 1996 and February 1997) aboard the R/V *Seward Johnson*, scientists from the Woods Hole Oceanographic Institution studied the deep mixing processes in the Brazil Basin. Two instrument systems were used in this experiment: the tracer injection and sampling system, and the High resolution Profiler (HRP). The HRP measurements complement those obtained by the tracer sampling system, providing independent estimates of the turbulent and diffusive mixing occurring in the study area.

During the cruises, the HRP was used to make two zonal sections across the basin, provide data used to select the tracer injection site, and explore the jagged terrain near the Mid-Atlantic Ridge. The HRP component of the work at sea, an instrument description, data return and some preliminary results are presented in this report.

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